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INVESTIGATION OF THE RELATIONSHIP BETWEEN BOILER WATER CHEMISTRY AND TURBINE BLADE PITTING

Final Report of
NBTL Project A-348
S2007-06-02, Task 0613

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From: Commander, Philadelphia Naval Shipyard
(Naval Boiler and Turbine Laboratory)
To: Chief, Bureau of Ships

Subj: Investigation of the Relationship Between Boiler Water Chemistry and Turbine Blade Pitting; Final Report of (NBTL Project A-348) (SR007-06-03, Task 0613)

Ref: (a) BUSHIPS ltr S007-06-03 Ser 634A-294 of 20 Sep 1960
(b) NBTL Chemistry Branch (Code 2764) Bi-Monthly Progress Reports from January 1961 through March 1962
(c) Enclosure (1) of USNEES ltr H2/9440(942) - Rept 610619A of 9 May 1961
(d) Enclosure (1) of USNEES ltr H2/10330(942) - Rept 940619B of 24 April 1962

Encl: (1) Analyses of boiler water and superheater inlet steam condensate samples from a 600 psi plant boiler
(2) Analyses of boiler water and superheater inlet steam condensate samples from the LPH-2 and DDG-15 boilers
(3) Analyses of boiler water, superheater inlet and superheater outlet steam condensate samples from the LPH-2 boiler
(4) Analyses of boiler water, superheater inlet and superheater outlet steam condensate samples from the LPH-2 boiler

1. During inspections of the propulsion machinery aboard a number of ships, it was found that severe pitting had taken place on the diaphragms and on the blades, both stationary and rotating, in the superheated stages of the turbines. The pitting apparently resulted from the materials in the boiler water that carried over with the steam and deposited on the turbine blades. The damage appeared more prevalent in turbines operating on steam supplied by boilers with integral superheaters. Evidence of this pitting was noted on ships with 600 psi boilers, treated with Navy Boiler Compound, as well as on ships with 1200 psi boilers, employing the split water treatment (10 to 25 ppm of phosphate and pH 10.4 to 11.0). In reference (c), it was reported that sodium chloride was the most corrosive compound to turbine blades of the several chemicals and chemical mixtures which can originate from boiler water solids. Work reported in reference (d) indicated "that some pitting is caused by the presence of sodium chloride in steam in quantities which are presently considered acceptable (0.2% carryover of a boiler water containing 500 ppm (8.5 equivalent parts per million) of NaCl)". The specification regarding moisture carryover on shipboard boilers requires

that not more than 3 ppm (0.25%) of total dissolved solids be carried over at 120% of full power and a water level of 3.0 to 3.5 inches with total dissolved solids of 1150-1175 ppm in the boiler water of which 500 to 550 ppm (14.1 to 15.5 epm) are present as the chloride ion. However, it is hardly likely that a ship would be operated under these conditions for any length of time except in an emergency.

2. The Naval Boiler and Turbine Laboratory was authorized by reference (a) to analyze the steam entering and leaving the superheater to establish the identity and concentrations of those materials which originate in the boiler water and are carried over with the steam that may deposit on the turbine blades. In order to provide a means for correlating the composition of the boiler water dissolved solids with those of the steam condensate, the boiler water from which the steam is generated should be analyzed as well as the steam condensate. These tests should be conducted on Laboratory boilers during actual operation.

3. The Laboratory selected two prototype boilers, with integral superheaters, for this evaluation as follows: The LPH-2, a 600 psi boiler and the DDG-15, a 1200 psi boiler. Sampling lines were installed before and after the superheaters on these boilers. Since the total dissolved solids content of steam condensate is extremely low under normal boiler operation, it was necessary to develop special analytical procedures for use with the Beckman Flame Spectrophotometer, model [illegible], and the [illegible] "DU" Spectrophotometer in order to determine the minute quantities of boiler water constituents present in the steam condensate. All data obtained during this evaluation were reported periodically by [illegible] (b).

4. Tests conducted on the DDG-15 and LPH-2 boilers as well as on plant boilers showed that the steam from these boilers was of extremely high purity under normal operating conditions and therefore meaningful data was not obtainable. In order to obtain more meaningful data on the solids concentrations in the steam condensate, analyses were subsequently conducted only during "end-point" moisture carryover evaluations on the DDG-15 and LPH-2 boilers when they were steamed at overload and high water levels with high boiler water dissolved solids permitting temporary carryover. Preliminary analyses were conducted by analyzing only for the sodium ion in the boiler water and the steam condensate at the superheater inlet and outlet. Results showed that the sodium concentration in the steam at the superheater inlet was higher than at the outlet suggesting that soluble salts remain in the superheater. However, this phenomenon has also been experienced in industrial plant boilers and was attributed to poor sampling of the superheated steam. It is believed that the solids carried over in the superheated steam are deposited on the surface of the sampling line due to the inability of the superheated steam to retain salts in vaporous form when the steam temperature is reduced.

5. Since it was reported by references (c) and (d) that turbine blade corrosion was primarily due to sodium chloride, sufficient amounts of this salt were added to the boiler water of a 600 psi plant boiler to yield about 1 epm of chloride. The phosphate ion concentration was maintained at 10-25 ppm. Boiler water and saturated steam condensate samples, drawn simultaneously, were analyzed for sodium, chloride, phosphate, soluble iron, silica, conductivity and pH. Samples were drawn several times daily. Presented in enclosure (1) are analyses of boiler water and steam condensate considered representative of data obtained during 3 separate days. Results of these analyses indicate the following:

a. Based on the sodium content in the boiler water and condensate, carryover is negligible. However, based on the chloride concentration in the condensate and the boiler water, carryover appears high. Although more chloride ion was found present than sodium ion, it was presumed that the analytical procedure for the chloride determination was not as reliable as the flame photometric determination for sodium.

b. In general, these data appear to be inconclusive since no moisture carryover was indicated on this boiler.

It is of interest to note that some soluble iron, even though in very small quantities, is carried over with the steam.

6. More meaningful information was obtained only during moisture carryover "end-point" evaluations on the LFH-2 and HSG-15 test boilers [illegible] they did not carry over at specification conditions. During "end-point" runs, the boilers were operated at overload with high boiler water dissolved solids and the steam drum water levels raised sufficiently to produce temporary solids carryover beyond permissible limits. These tests were originally conducted for the purpose of evaluating steam drum internals. During the temporary moisture carryover conditions, simultaneous samples of saturated steam condensate and boiler water were drawn and analyzed for sodium, chloride, phosphate, soluble iron, silica, conductivity and pH. Results of analyses of two "end-point" runs on each boiler and the percentage carryover, based on the individual constituents present in the steam condensate and boiler water are presented in enclosure (2). Results of these analyses indicate the following:

a. For practical purposes, the percentages of moisture carryover based on the sodium, chloride and phosphate concentrations as well as conductivity, are about the same. Based on these constituents, there is no preferential carryover in either the 600 or 1200 psi boilers. It is of interest to note that the percentage carryover calculated from the conductivity readings, which are a measurement of total dissolved solids, is in fairly good agreement with the calculated percentages based on the individual constituents.

b. Although the percentage carryover based on the iron and silica concentrations in the condensate and boiler water was very high, the results are not considered meaningful and should not be used as criteria for moisture carryover for the following reasons:

(1) The concentrations are expressed in the parts per billion range and the accuracy of the spectrophotometric procedure is questionable in these extremely low concentrations.

(2) Despite careful filtering of the samples for the determination of soluble iron, some particles passed through the filter to yield high iron values in the steam condensate. In addition, some iron could have been picked up in the saturated steam line and would, therefore, not be representative of normal boiler water solids carryover.

(3) The minute amounts of silica found in the steam are not significant enough to cause concern, particularly since silica is not a problem on a marine power plant installation. In addition, it is not known whether the presence of silica in the steam is due to mechanical carryover or to its vaporized state.

c. The pH values of the condensate indicate [illegible] alkalinity.

7. Several runs were conducted on the [illegible]-2 boiler to determine water level "end-points" at overload with various concentrations of di[illegible] solids in the boiler water. Data were taken to determine the relationship of the individual solids concentrations in the saturated steam (superheater inlet) and those of the boiler water. In addition since it was desired to determine the relationship of solids in saturated steam (superheater inlet) condensate and solids in superheated steam (superheater outlet) condensate, simultaneous boiler water, superheater inlet and outlet steam condensate samples were collected and analyzed for sodium, chloride, phosphate, soluble iron, silica, conductivity and pH. Note that during one of the moisture carryover runs, the boiler water solids were more than twice the concentration of salt contaminants normally added to the boiler water for moisture carryover evaluations. Results of analyses are tabulated in enclosure (3). These data show that:

a. Based on sodium, chloride and phosphate concentrations as well as conductivity, there is generally no preferential carryover. However, during runs No. 9 and No. 10 the phosphate ion appeared to carry over at considerably higher ratios than the other constituents. This condition had not been noted previously.

b. Although the percentages of carryover based on iron and silica concentrations in the condensate and boiler water are very high, the results are not considered meaningful as discussed previously.

c. The percentage solids carryover in the superheated steam appeared low when compared with that of the saturated steam condensate samples. This would suggest that the solids entrained with the steam leaving the boiler are deposited on the superheater tube surfaces. Although no work was done at the Laboratory to establish the absence of solids deposition on the superheater surfaces, a number of technical articles appeared in the literature stating that low solids content in the superheated steam does not necessarily mean that salts are being deposited on the steam sides of the superheater.

d. Conductivity values of the superheater outlet samples were high and in complete disagreement with ratios of condensate to boiler water based on chloride and sodium ion concentrations. However, this should not form a basis for solids carryover because the disagreement is due to the fact that steam samples from the superheater outlet are not degassed and therefore, no carbon dioxide and ammonia were removed. Experience has shown that as much as 95% of the conductivity value can be due to the dissolved gases in the undegassed condensate sample.

8. Since moisture carryover based on phosphate concentrations in the saturated steam condensate as compared to the boiler water did not always agree with carryover based on sodium, chloride and conductivity, additional runs were conducted on the LPB-2 test boiler to determine whether phosphates are carried over preferentially with the steam. Results obtained are presented in enclosure (4) and show that the phosphate ion is not carried over preferentially with the steam. All other results were generally the same as obtained during previous runs.

9. Based on results obtained during the evaluation on laboratory test and plant boilers, it is concluded that:

a. There is no preferential carryover of sodium chloride with the steam.

b. No carryover from alkalinity would result in boilers receiving the proper boiler water treatment.

c. Carryover should not be a problem on boilers at normal water levels with normal boiler water dissolved solids even at overload steaming conditions.

d. No preferential carryover of salts normally found in 600 and 1200 psi boilers should occur.

10. Although laboratory tests showed that only very small amounts of boiler water solids are carried over with the steam under normal operation, excessive carryover has been known to have occurred aboard ship due to maloperation and/or improper boiler water treatment and improper steam baffle design. Even under these conditions, the sodium chloride in the

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boiler water will not carry over preferentially, and if sea water contamination in the boiler water is kept to a minimum, no appreciable turbine blade corrosion problems should be anticipated. With proper boiler operation and effective steam separators, no carryover should take place even with relatively high chloride concentrations in the boiler water. However, since moisture carryover is a function of the total solids content in the boiler water, sea water contamination should be kept to a minimum.

11. In order to minimize shipboard turbine blade pitting and corrosion, the following conditions should be maintained:

a. Limit the chloride concentration in the boiler water to 2 epm maximum.

b. Maintain proper boiler water treatment and blow down the boilers frequently to keep the water solids to a minimum.

c. Do not steam boilers at high water levels except in an emergency.

d. Proper steam baffle design to keep moisture carryover to a minimum.

J. W. MURDOCK
BY DIRECTION

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ANALYSES OF BOILER WATER AND SUPERHEATER INLET
STEAM CONDENSATE SAMPLES FROM A 600 PSI PLANT BOILER

	Run No.	Na (ppm)	Cl (ppm)	PO_4 (ppm)	Fe Soluble (ppb)	SiO_2 (ppb)	Conductivity* (mmhos)	pH
Boiler Water	1	82	35.5	18	175	18	-	10.7
Condensate	1	0.003	0.61	0.06	5	0.05	-	8.7
Carryover - %	1	0.004	1.7	0.3	2.9	0.3	-	-
Boiler Water	1	81	35.5	20	166	20	-	10.7
Condensate	1	0.003	0.36	0.10	10	0.10	-	8.7
Carryover - %	1	0.004	1.0	0.5	6.0	0.5	-	-
Boiler Water	1	80	32.6	15	80	15	-	10.7
Condensate	1	0.003	0.14	0.09	25	0.09	-	8.7
Carryover - %	1	0.004	0.4	0.6	18	0.6	-	-
Boiler Water	1	76	32.6	15	60	15	-	10.7
Condensate	1	0.004	0.18	0.09	16	0.09	-	8.7
Carryover - %	1	0.005	0.6	0.6	23	0.6	-	-
Boiler Water	2	74	28.9	15	200	40	515	11.0
Condensate	2	0.011	0.15	0.1	[illegible]	[illegible]	[illegible]	[illegible]
Carryover - %	2	0.015	0.6	0.7	8.5	30	-	-
Boiler Water	2	73	30.4	15	175	60	530	11.0
Condensate	2	0.019	0.18	0.1	5	6	[illegible]	-
Carryover - %	2	0.026	0.6	0.7	2.9	10	-	-
Boiler Water	2	72	26.9	15	295	30	510	11.0
Condensate	2	0.003	0.16	0.1	5	4	6.0	8.9
Carryover - %	2	0.004	0.6	0.7	1.7	13	-	
Boiler Water	2	71	28.9	15	188	20	515	11.0
Condensate	2	0.009	0.18	0.1	5	7	6.0	8.8
Carryover - %	2	0.013	0.6	0.7	2.7	35	-	-
Boiler Water	3	45	20.5	8	750	80	325	10.7
Condensate	3	0.002	0.07	0.1	35	8	6.7	8.5
Carryover - %	3	0.004	0.3	1.3	4.7	10	-	-
Boiler Water	3	45	20.5	8	440	80	325	10.8
Condensate	3	0.002	0.07	0.1	50	4	6.7	8.8
Carryover - %	3	0.004	0.3	1.3	11	5	-	-
Boiler Water	3	45	20.5	8	525	80	320	10.8
Condensate	3	0.002	0.07	0.1	55	3	6.7	8.5
Carryover - %	3	0.004	0.3	1.3	10	3.8	-	-

* The conductivity of the condensate sample is high due to dissolved gases in the steam. A degasser was not available on this installation.

Enclosure (1)

ANALYSES OF BOILER WATER AND SUPERHEATER INLET STEAM CONDENSATE SAMPLES FROM THE LPE-2 AND DDG-15 BOILERS

Sample Source	Run No.	Na (ppm)	Cl (ppm)	PO_4 (ppm)	Soluble Fe (ppb)	SiO_2 (ppb)	Conductivity (μmhos)	pH
LPE-2 Boiler								
Condensate	4	0.56	0.73	0.08	11.2	3.4	2.5	6.1
Boiler Water	4	425	538	70	105	50	2400	10.8
Carryover - %	4	0.13	0.14	0.11	10.7	6.8	0.10	-
Condensate	5	1.12	1.36	0.15	12.9	3.4	4.7	6.1
Boiler Water	5	415	513	60	145	50	2250	10.7
Carryover - %	5	0.27	0.27	0.25	8.9	6.8	0.21	-
DDG-15 Boiler								
Condensate	6	0.50	0.40	0.14	14.0	3.4	2.4	7.2
Boiler Water	6	276	301	70	110	10	1550	10.9
Carryover - %	6	0.18	0.13	0.20	12.7	34	0.15	-
Condensate	7	0.73	0.60	0.07	5.6	3.4	3.5	7.4
Boiler Water	7	500	627	60	115	60	2300	10.9
Carryover - %	7	0.15	0.10	0.12	[illegible]	[illegible]	[illegible]	-

Enclosure (2)

ANALYSES OF BOILER WATER, SUPERHEATER INLET AND SUPERHEATER OUTLET STEAM CONDENSATE SAMPLES FROM THE LFS-2 BOILER

Sample Source	Run No.	Na (ppm)	Cl (ppm)	PO_4 (ppm)	Soluble Fe (ppb)	SiO_2 (ppb)	Conductivity (mmhos)	pH
Superheater Inlet	8	5.42	6.29	1.14	10.8	1.7	28.1	6.5
Boiler Water	8	425	524	75	23	45	2500	10.9
Carryover - %	8	1.28	1.20	1.52	38.5	3.8	1.12	-
Superheater Inlet	8	2.17	2.43	0.40	10.3	1.7	10.7	7.3
Boiler Water	8	425	517	80	38	40	2510	10.9
Carryover - %	8	0.51	0.47	0.50	27.1	4.3	0.43	-
Superheater Inlet	8	5.19	5.73	1.00	25.7	2.3	26.1	6.0
Boiler Water	8	425	506	80	104	40	2500	10.9
Carryover - %	8	1.22	1.13	1.25	24.7	5.8	1.04	-
Superheater Inlet	8	6.53	8.08	1.16	26.1	1.74	36.9	7.6
Boiler Water	8	450	610	90	[illegible]	[illegible]	[illegible]	——
Carryover - %	8	1.45	1.32	1.29	12.4	4.4	1.51	-
Superheater Inlet	8	9.69	11.95	1.74	43.5	2.32	55.7	[illegible]
Boiler Water	8	627	785	140	185	60	3400	11.2
Carryover - %	8	1.55	1.52	1.24	23.5	3.9	1.64	-
Superheater Inlet	9	1.57	1.27	0.56	19.6	5.5	6.6	5.6
Boiler Water	9	445	441	45	135	60	2500	10.85
Carryover - %	9	0.35	0.29	1.24	14.5	9.3	0.26	-
Superheater Outlet	9	0.2	0.18	0.1	15	4	11.9	6.8
Boiler Water	9	445	441	45	135	60	2500	10.85
Carryover - %	9	0.04	0.04	0.22	11.1	6.[illegible]	0.46	-
Superheater Inlet	10	3.00	3.63	0.34	16.2	4.5	14.7	5.7
Boiler Water	10	1400	1790	35	68	100	6850	10.84
Carryover - %	10	0.22	0.20	0.97	23.8	4.5	0.21	-
Superheater Outlet	10	0.1	0.04	0.01	10	3	14.0	8.65
Boiler Water	10	1400	1790	35	68	100	6850	10.85
Carryover - %	10	0.007	0.002	0.03	14.7	3	0.20	-

Enclosure (3)

ANALYSES OF BOILER WATER, SUPERHEATER INLET AND SUPERHEATER OUTLET STEAM CONDENSATE SAMPLES FROM THE LPH-2 BOILER

Sample Source	Run No.	Na (ppm)	Cl (ppm)	PO_4 (ppm)	Soluble Fe (ppb)	SiO_2 (ppb)	Conductivity (mhos)	pH
Superheater Inlet	11	1.4	1.17	0.5	5	2	6.5	7.5
Boiler Water	11	440	431	130	60	60	2420	11.0
Carryover – %	11	0.32	0.27	0.38	8.3	3.3	0.27	–
Superheater Outlet	11	0.65	0.18	0.05	5	4	8.4	8.6
Boiler Water	11	440	431	130	60	60	2420	11.0
Carryover – %	11	0.014	0.042	0.038	8.3	6.7	0.35	–
Superheater Inlet	11	6.3	6.4	1.7	17	3	31.0	9.0
Boiler Water	11	440	438	130	55	60	2400	11.0
Carryover – %	11	1.43	1.46	1.31	30.9	5.0	1.29	–
Superheater Outlet	11	0.4	0.29	0.25	20	4	9.8	8.6
Boiler Water	11	440	438	130	55	60	2400	11.0
Carryover – %	11	0.09	0.07	0.19	36.4	5.7	0.41	–
Superheater Inlet	12	27.9	38.2	2.9	[illegible]	[illegible]	[illegible]	[illegible]
Boiler Water	12	1760	2199	190	65	90	6200	11.0
Carryover – %	12	1.59	1.74	1.53	27.0	7.6	1.79	–
Superheater Outlet	12	0.9	0.65	0.20	5	2	15.0	--
Boiler Water	12	1760	2199	190	65	90	8200	11.0
Carryover – %	12	0.05	0.03	0.11	7.9	2.2	0.18	–

Enclosure (4)